CLINICAL ARTICLE

Comparing Bone Graft Techniques for Interbody Fusion through a Posterior Approach for Treating Mid-Thoracic Spinal Tuberculosis: A Retrospective Analysis

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Objective: Mid-thoracic spinal tuberculosis is prone to kyphotic deformities and neurologic impairment. Posterior approach can effectively restore the spinal stability by reconstructing the anterior and middle spinal columns. Titanium mesh cages (TMC), allogeneic bone (ALB), and autogenous bone (AUB) are three main bone graft struts. We aimed to compare the therapeutic efficacy of three bone graft struts, for anterior and middle column reconstruction through a posterior approach in cases of mid-thoracic spinal tuberculosis.

Methods: Hundred and thirty seven patients with thoracic spinal tuberculosis who had undergone a posterior approach from June 2010 to December 2018 were enrolled. Of them, 46 patients were treated using a titanium mesh cage (TMC group), 44 with allogenic bone grafts (ALB group), and 47 using autogenous bone grafts (AUB group). The following were analyzed to evaluate clinical efficacy: visual analogue scale (VAS) values, erythrocyte sedimentation rate (ESR), C-reactive protein (CRP) levels, kyphotic Cobb's angle, operation duration, intraoperative blood loss, improvement in American Spinal Injury Association (ASIA) grade and in the mental component summary (MCS) and physical component summary (PCS) of Short Form-36 (SF-36), duration of bone graft fusion. The data of the three groups were compared by way of variance analysis, followed by the LSD-t test to compare each group. A repeated measures ANOVA was used to analyze the dates of pre-, postoperative and final follow-up.

Results: The follow-up duration was at least 3 years. All patients achieved a complete cure for spinal TB. Neurological performance and quality of life were remarkably improved at the final follow-up. The intraoperative blood loss, operation time and VAS values 1 day postoperatively for TMC group and ALB group were significantly lower than those in AUB group ($P < 0.05$). The duration of bone graft fusion in ALB group (18.1 ± 3.7 months) was longer than that in TMC group and AUB group (9.5 ± 2.8 and 9.2 ± 1.9 months) ($P < 0.05$). No significant intergroup differences were observed in terms of age or preoperative, 3-months postoperative, and final follow-up indices of ESR and CRP among the three groups ($P > 0.05$). At the final follow-up, the correction loss was mild (2.1 ± 0.9, 2.2 ± 1.0, 2.1 ± 0.8) and Cobb's angles of the three groups were 20.1 ± 2.9, 20.5 ± 3.2, 20.9 ± 3.4, respectively, which were remarkably rectified in comparison with the preoperative measurements ($P < 0.05$).

Conclusions: In terms of postoperative recovery and successful fusion rate of bone graft, it seems that posterior instrumentation, debridement, and interbody fusion with titanium mesh cages are more effective and appropriate surgical methods for mid-thoracic spinal tuberculosis.

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Introduction

Tuberculosis (TB) is an infectious disease that is among the top 10 causes of death worldwide. As COVID-19 continues to wreak havoc, TB control around the globe has been paid less importance. As a result, the death rate of TB sees a first year-on-year growth (5.6%) since 2005, which reverses the progress in reducing the TB death rate over the years.[1] China is one of the countries that has long suffered from TB.[2] The emergence of antibiotic-resistant bacteria, compounded with the COVID-19 pandemic, has led to an increase in the incidence rate of TB. As a systemic disease, many organ systems may be affected by mycobacterium tuberculosis (MTB), with the musculoskeletal system being one of the most commonly affected systems. The spine is the most common site of musculoskeletal involvement, accounting for about half of the cases.

For the treatment of spinal tuberculosis, the combination of anti-TB drugs remains the cornerstone of disease management and reducing the incidence of MDR-TB is the goal of the combined drug therapy.[3] However, for patients presenting with neurological deficits or severe kyphotic deformity, surgical intervention is recommended.[4,5] With the wide application of posterior internal fixation technology, correcting spinal deformity simultaneously through one incision, by achieving stable fusion, debridement, and decompression, has become the first interventional choice by spinal surgeons over the past decade. The theory of Denis's three columns of the spine illustrates the importance of reconstructing spinal stability.[6] Spinal tuberculosis usually causes kyphotic deformities by damaging the anterior and middle spinal columns. Pedicle screws across the three columns can provide reliable support, and combined interbody fusion can restore spinal stability. Autogenous ribs, ilium bone, and allograft bone blocks are common graft materials for interbody fusion,[7] however, it is still disputed BY clinicians about which graft to reconstruct the anterior and middle column of the spine to restore spinal stability in patients with thoracic spinal tuberculosis and kyphosis. Also, few studies have compared the therapeutic effect of different intervertebral fusion modalities in reconstructing the anterior and middle columns through a posterior-only surgery in the surgical treatment of spinal tuberculosis.

In this study, 137 patients with mid-thoracic tuberculosis who underwent one-stage posterior approach were followed up for more than 3 years. The aims of this research are: (i) to elucidate the characteristics of mid-thoracic tuberculosis and necessity of surgical treatment; (ii) to introduce the advantages of posterior approach in the treatment of mid-thoracic tuberculosis; and (iii) to compare the efficacy of three bone graft techniques (titanium mesh cage, allogeneic graft bone, and autogenous graft bone) in reconstructing spinal stability through the posterior approach in patients with mid-thoracic spinal tuberculosis.

Methods

Patient Population

This study was approved by the Ethics Review Committee of Xiangya hospital Central South University (No. 202206144).

The inclusion criteria were as follows: (i) patients with confirmed spinal TB, defined as patients whose intraoperative lesion biopsy revealed tuberculosis; (ii) severe or progressive neurological impairment, spinal instability or deformity; (iii) progressively worsening back pain with no benefits with conservative treatment; (iv) lesions to be addressed surgically involving ≤2 adjacent segments; and (v) at least a 3-year follow-up period with complete data.

Exclusion criteria were as follows: (i) patients with active systemic TB; (ii) accompanying huge flow abscess; (iii) a history of thoracic spinal surgery or congenital scoliosis; and (iv) patients with surgical contraindications such as severe coagulation disorders.

Data on 137 patients with thoracic tuberculosis, from June 2010 to December 2018, who underwent posterior instrumentation, debridement, decompression, interbody fusion using a titanium mesh cage (46 patients), allogeneic bone graft (44 patients), or autogenous bone graft (47 patients) were analyzed. Patients treated with titanium mesh cages, allogeneic bone grafts, or autogenous bone grafts were divided into three groups and marked as TMC group, ALB group and AUB group, respectively. Unfortunately, it was difficult to randomly select a surgical treatment method in clinical practice. Therefore, in our study, all patients treated with titanium mesh cage were collected more recently, while the patients treated with allogeneic bone graft and autogenous bone graft were collected earlier.

The follow-up time, mean operation time, mean blood loss, and preoperative, postoperative, and final follow-up indices of visual analogue scale (VAS) scores, erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), Cobb angle, of the three groups were analyzed and compared (Table 1). The main clinical manifestations were back pain, systemic symptoms of TB (low fever, night sweats, weakness, weight loss), varying degrees of kyphotic deformity and neurological deficits. Combined with medical history and physical examination, diagnosis of spinal TB can be established from laboratory examinations, imaging findings, and tissue biopsy. Pulmonary computed tomography (CT) scans, consecutive sputum smears, and cultures were conducted to

TABLE 1 Basic clinical data and evaluation indexes comparison of each group

Basic clinical data of patients	TMC group	ALB group	AUB group	Statistical value	$P_{TMC-ALB}/P_{TMC-AUB}/P_{ALB-AUB}$
Age (years)	45.4 ± 14.6	43.8 ± 14.5	45.7 ± 16.8	$F = 0.20$, $P = 0.816$	–/–/–
Mean follow-up time (months)	40.4 ± 2.4	40.9 ± 2.5	40.8 ± 2.8	$F = 0.47$, $P = 0.627$	–/–/–
Duration of operation (min)	226.0 ± 20.0	218.4 ± 15.9	309.8 ± 20.3	$F = 333$, $P = 0.000$	0.060/0.000/0.000
Intraoperative blood loss (ml)	539.9 ± 42.2	553.5 ± 31.2	642.4 ± 48.6	$F = 84$, $P = 0.000$	0.122/0.000/0.000
VAS					
Preoperative	5.5 ± 1.0	5.5 ± 0.9	5.7 ± 1.0	$F = 0.56$, $P = 0.572$	–/–/–
Postoperative	6.1 ± 0.7[a]	5.9 ± 0.8[a]	7.3 ± 0.8[a]	$F = 0.85$, $P = 0.000$	0.205/0.000/0.000
Final follow-up	1.2 ± 0.7[a]	1.2 ± 0.8[a]	1.3 ± 0.8[a]	$F = 0.66$, $P = 0.521$	–/–/–
ESR (mm/h)					
Preoperative	66.9 ± 31.9	65.9 ± 31.6	64.4 ± 31.2	$F = 0.07$, $P = 0.930$	–/–/–
Three months postoperative	16.5 ± 7.5[a]	17.5 ± 6.9[a]	17.1 ± 9.5[a]	$F = 0.06$, $P = 0.941$	–/–/–
Final follow-up	11.2 ± 3.9[a]	12.6 ± 4.0[a]	11.8 ± 4.1[a]	$F = 1.47$, $P = 0.234$	–/–/–
CRP (mg/L)					
Preoperative	24.4 ± 27.8	25.2 ± 23.4	23.4 ± 20.3	$F = 0.07$, $P = 0.935$	–/–/–
Three months postoperative	8.3 ± 8.1[a]	7.9 ± 7.2[a]	8.5 ± 6.8[a]	$F = 0.06$, $P = 0.947$	–/–/–
Final follow-up	7.6 ± 2.9[a]	7.8 ± 3.4[a]	7.6 ± 3.0[a]	$F = 0.07$, $P = 0.930$	–/–/–
Cobb angle (°)					
Preoperative	25.3 ± 3.5	25.7 ± 3.7	25.0 ± 3.1	$F = 0.48$, $P = 0.618$	–/–/–
Postoperative	18.0 ± 2.9[a]	18.3 ± 3.3[a]	18.9 ± 3.4[a]	$F = 0.85$, $P = 0.429$	–/–/–
Final follow-up	20.1 ± 2.9[a]	20.5 ± 3.2[a]	20.9 ± 3.4[a]	$F = 0.77$, $P = 0.464$	–/–/–
Cobb angle loss (°)	2.1 ± 0.9	2.2 ± 1.0	2.1 ± 0.8	$F = 0.41$, $P = 0.662$	–/–/–
Time of bone graft fusion (months)	9.5 ± 2.8	18.1 ± 3.7	9.2 ± 1.9	$F = 218$, $P = 0.000$	0.000/0.076/0.000

Notes: [a] Analyzed by repeated measures ANOVA, compared with preoperatively, $P < 0.05$.

exclude patients with active systemic TB. Plain radiographs, CT scans, and magnetic resonance imaging (MRI) of the affected spinal area were used to determine the location of the lesion and assess the condition of canal encroachment and cord compression. Electromyography (EMG) is essential in patients with neurological deficits. The American Spinal Injury Association (ASIA) classification was used to evaluate neurological status (Table 2). The Short Form 36 (SF-36) survey which is a form to score the patient reported health-related quality of life (HRQOL) was used as the major outcome measure in this study.[8] It consists of two component scores (MCS, mental component summary; PCS, physical component summary) and eight domains, working together on reporting mental and physical health.

Preoperative Preparation

For patients with progressive neurological deterioration, emergency surgery is necessary after the exclusion of surgical contraindication. Other patients received quadruple standard antituberculosis medical therapy for at least 2–4 weeks, including isoniazid (5 mg/kg/day, < 300 mg/day), rifampicin (10 mg/kg/ day, <1200 mg/day), and pyrazinamide (30 mg/kg/day, <2000 mg/day), and ethambutol (15 mg/kg/ day, <2500 mg/day). The surgery was performed once ESR and CRP returned to normal or decreased significantly, and hypoproteinemia, anemia, or electrolyte disturbances were corrected. Patients with chronic diseases, such as hypertension or diabetes, controlled their blood pressure and blood glucose under the guidance of a relevant specialist.

TABLE 2 ASIA grade for neurological status valuation

			Final follow-up				
Preoperative		TMC group	A	B	C	D	E
Paragplegia	A	4			1	3	
	B	4				2	2
Paraparesis	C	9					9
	D	13					13
	E	16					16
			Final follow-up				
		ALB group	A	B	C	D	E
Paragplegia	A	2			2		
	B	6				5	1
Paraparesis	C	8					8
	D	12					12
	E	16					16
			Final follow-up				
		AUB group	A	B	C	D	E
Paragplegia	A	4			2	2	
	B	5				3	2
Paraparesis	C	10					10
	D	9					9
	E	19					19

According to the results of the imaging examination, all patients received a back tag, and thoracic radiography was performed.

Surgical Procedures

All patients received general anesthesia and underwent surgery in a prone position. The surgical incision location and range were determined based on the location on the X-ray film.

In the TMC group, the lamina, facet joints, and transverse processes were exposed after subperiosteal dissection of the paravertebral muscle. On the affected side, the ribs lateral to the transverse process were exposed to facilitate lesion removal followed by the placement of the pedicle screws. The fixation range included diseased vertebras and 1–2 upper and lower normal vertebrae, especially in the thoracolumbar junction. A temporary rod was placed laterally on the side of the lesion to stabilize the spine. The spinous process and lamina of the affected vertebrae were resected along with the pedicles, facet joints, and partial ribs on the side of the focus, where bone destruction or lesions were relatively severe, to establish a channel for bone graft fusion and lesion removal. To obtain a more suitable operating space and broader view, the intercostal vessels and intercostal nerves of the affected segments were sacrificed. Then, the paravertebral abscess was cleared, and the sequestrum was wiped off using different curettes. The lesion area was thoroughly rinsed with saline and hydrogen peroxide. The deep pus and necrotic tissue were then flushed and drained using a catheter. After debridement, replacement of the temporary rod with a permanent rod was performed, nuts were locked, and intervertebral space was dilated for spine stabilization and kyphosis correction. The healthy lamina, spinous processes, ribs, and allografts were clipped to osseous granules by a rongeur. An appropriate length and shape of the mesh cage filled with osseous granules were implanted into the bone graft bed for interbody fusion. A titanium rod was installed on the affected side, and the bone graft was held and clamped properly. Bone graft fusion was performed posterior to the lamina and interarticular process. For antibiotic application, 1.0 g of streptomycin and 0.3 g of isoniazid were scattered to the focused area. Finally, a drainage tube was placed for the wounds, and the incision was closed.

In the ALB group the allogeneic bone block was clipped to a specific length and size and placed in the interbody after debridement. In the AUB group, autogenous bone grafts were harvested from the ilium for interbody fusion. The patients were required to undergo an autologous iliac crest bone graft harvesting operation in a supine position. The other procedures were the same as those in TMC group.

The biopsy specimens were sent for bacterial and fungal culture and pathological examination.

Postoperative Management

Antibiotics (first or second generation cephalosporins) were used for 48 or 72 h. The lower extremity movements and sensations were closely monitored. The drainage tube was usually removed once the drainage flow was below 20 ml/day. All patients were requested to get out of bed under the protection of a brace following strict bed rest for 4 weeks postoperatively. The brace apparatus was placed for at least 6 months. Implant position and kyphosis correction were observed using radiography and/or CT scans after surgery. Anti-tuberculosis chemotherapy and hepatic protection treatment were continued for 12–18 months. All patients should be given early rehabilitation training and hyperbaric oxygen therapy to improve neurological status. Perioperative complications were recorded.

Follow-up and Efficacy Evaluation Indexes

The patients were followed up for at least 3 years. The follow-up interval was once every 3 months within the first year after surgery and once every 6 months within the second and third year after surgery. The follow-up items included symptoms (fever, VAS score for back pain, and ASIA grade for neurological function) and blood parameters (ESR and CRP) and various complications. Routine lateral and anteroposterior radiographs or CT were also obtained to assess the placement of the graft and instrumentation. Kyphotic angles measured on lateral plain radiography, which was measured by the two lines parallel to the tangents of the upper endplate of T4 and the lower endplate of T12. CT were also used to gauge the degree of bony healing per the modified radiological criteria of Lee *et al.*[9]

Statistical Analysis

The SPSS 26.0 (IBM, Armonk, NY, USA) statistical software was applied for data analysis. The data of the three groups were compared by way of variance analysis first, followed by the LSD-t test to compare each group when the value of $P < 0.05$. A repeated measures ANOVA was used to analyze the date of pre-, postoperative and final follow-up. P values of <0.05 were accepted as significant.

Results

General Results

All surgical specimens confirmed tuberculous granuloma or caseous necrosis using pathological examinations, of which 46 cases were cultured positive for MTB. All patients were followed up for at least 3 years. The average follow-up time of three groups were 40.4 ± 2.4, 40.9 ± 2.5, 40.8 ± 2.8 months, respectively. All surgeries were performed successfully. No anesthetic accident or operative mortality was observed in any patient during hospitalization. No TB dissemination or progressive neurological deterioration occurred in any of the three groups during the follow-up duration.

Blood Loss and Operative Time

The mean operation time and intraoperative blood loss were respectively recorded as 226.0 ± 20.0 min and 539.9 ± 42.2 ml in the TMC group, 218.4 ± 15.9 min and 553.5 ± 31.2 ml in the ALB group, 309.8 ± 20.3 min and 642.0 ± 48.6 ml in the AUB group, which indicated that the values of the AUB group were greater than those of the TMC and ALB groups ($P < 0.05$).

Inflammation Indicators and Visual Analogue Scale

The ESR and CRP values returned to normal 3 months post-surgery. At the final follow-up, the VAS score of three groups was 1.2 ± 0.7, 1.2 ± 0.8,1.3 ± 0.8, respectively. Statistically significant differences were found between preoperative and the final follow-up values of ESR, CRP and VAS ($P < 0.05$). Nevertheless, VAS values 1 day postoperatively were higher in the AUB group than those of the TMC and ALB groups. No significant differences in ESR, CRP, and VAS were observed among the three groups at the final follow-up.

Neurological Function

According to the ASIA grading system, the neurologic status of all patients improved to a certain extent (Table 2). In the TMC group, the full neurological recovery rate for paraplegia (ASIA grades A and B) was 25% (2/8), while the full neurological recovery rates for paraplegia in the ALB and AUB groups were 12.5% (1/8) and 22% (2/9), respectively. The full neurological recovery rate of all patients with paraparesis (ASIA grades C and D) in the three groups was 100%. There were no statistically differences in the rates of neurological function recovery among the groups for either paraplegia or paraparesis (Table 2).

Health-Related Quality of Life

Statistically significant differences were found between preoperative and the final follow-up values of SF-36 scores ($P < 0.05$). There were no significant differences in the MCS and PCS scores of the SF-36 scale among the three groups (Table 3).

Kyphotic Cobb's Angle

Spinal stability was restored in all cases. The immediately recorded postoperatively Cobb's angle of three groups, decreased to 18.0° ± 2.9, 18.3° ± 3.3, 18.9° ± 3.4 respectively from 25.3 ± 3.5, 25.7 ± 3.7, and 25.0 ± 3.1 preoperatively. At the final follow-up, the correction loss was mild (2.1 ± 0.9, 2.2 ± 1.0, 2.1 ± 0.8) and the Cobb's angles of the three groups were 20.1 ± 2.9, 20.5 ± 3.2, 20.9 ± 3.4, respectively, which remarkably rectified in comparison with the preoperative measurements ($P < 0.05$; Table 1). No significant differences were recorded in the correction loss among the three groups.

Fusion Time

The mean time of bone graft fusion was 9.5 ± 2.8, 18.1 ± 3.7 and 9.2 ± 1.9 months in three groups, respectively, indicating a longer allogeneic bone grafts' fusion period than that in the other two groups.

Complications

Superficial wound infection occurred in 11 cases (four in the TMC group, three in the ALB group, and four in the AUB group), which were cured after debridement, suturing, and anti-infection strengthening. Six patients in the AUB group complained of postoperative pain in the autogenous iliac bone extraction area, which was overcome by administering nonsteroidal anti-inflammatory drugs. Three patients in each of the groups experienced severe intercostal neuralgia, which was ultimately healed through nerve blocks. Catheter drainage through a minimally invasive incision and regular

TABLE 3 SF-36 scores of comparison of each group

		TMC group	ALB group	AUB group	Statistical value	$P_{TMC\text{-}ALB}/P_{TMC\text{-}AUB}/P_{ALB\text{-}AUB}$
Pre-op	PF	52.2 ± 36.4	53.4 ± 37.5	52.0 ± 38.7	$F = 0.18, P = 0.982$	–/–/–
	RP	38.0 ± 34.4	39.8 ± 35.5	41.5 ± 37.3	$F = 0.11, P = 0.898$	–/–/–
	BP	32.8 ± 10.2	32.3 ± 10.3	31.6 ± 10.1	$F = 0.15, P = 0.863$	–/–/–
	GH	14.6 ± 11.9	14.9 ± 11.7	13.6 ± 11.4	$F = 0.15, P = 0.863$	–/–/–
	PCS	34.4 ± 22.1	35.1 ± 22.8	34.7 ± 23.5	$F = 0.01, P = 0.990$	–/–/–
	VT	22.4 ± 11.0	21.8 ± 11.6	21.6 ± 11.4	$F = 0.06, P = 0.941$	–/–/–
	SF	33.4 ± 19.2	33.8 ± 19.4	32.4 ± 19.8	$F = 0.06, P = 0.942$	–/–/–
	RE	23.2 ± 19.7	23.5 ± 19.8	24.1 ± 22.7	$F = 0.02, P = 0.976$	–/–/–
	MH	25.7 ± 8.0	25.4 ± 9.0	27.6 ± 8.8	$F = 0.90, P = 0.407$	–/–/–
	MCS	26.2 ± 12.5	26.1 ± 13.3	26.4 ± 13.3	$F = 0.01, P = 0.992$	–/–/–
FFU	PF	87.9 ± 14.0[a]	86.6 ± 17.9[a]	86.5 ± 17.0[a]	$F = 0.11, P = 0.894$	–/–/–
	RP	85.3 ± 21.5[a]	82.4 ± 26.2[a]	83.5 ± 25.7[a]	$F = 0.17, P = 0.848$	–/–/–
	BP	91.6 ± 7.4[a]	91.9 ± 7.7[a]	90.1 ± 10.5[a]	$F = 0.56, P = 0.575$	–/–/–
	GH	72.2 ± 6.9[a]	70.9 ± 9.5[a]	71.4 ± 8.7[a]	$F = 0.27, P = 0.765$	–/–/–
	PCS	84.3 ± 11.2[a]	82.9 ± 14.0[a]	82.9 ± 14.4[a]	$F = 0.16, P = 0.854$	–/–/–
	VT	79.5 ± 5.9[a]	79.4 ± 6.8[a]	79.3 ± 7.3[a]	$F = 0.01, P = 0.988$	–/–/–
	SF	76.6 ± 6.2[a]	75.6 ± 7.1[a]	75.8 ± 7.1[a]	$F = 0.31, P = 0.738$	–/–/–
	RE	52.8 ± 18.0[a]	51.5 ± 19.6[a]	50.3 ± 19.5[a]	$F = 0.21, P = 0.813$	–/–/–
	MH	73.7 ± 7.9[a]	72.7 ± 9.7[a]	71.8 ± 9.4[a]	$F = 0.52, P = 0.596$	–/–/–
	MCS	70.7 ± 7.4[a]	69.8 ± 8.7[a]	69.3 ± 8.9[a]	$F = 0.32, P = 0.729$	–/–/–

Abbreviations: BP, bodily pain; GH, general health; MCS, mental component summary; MH, mental health; PCS, physical component summary; PF, physical functioning; Post-op, post-operation; Pre-op, pre-operation; RE, role-emotional; RP, role-physical; SF, social functioning; VT, vitality; *Notes*: [a] Analyzed by repeated measures ANOVA, compared with preoperatively, $P < 0.05$.

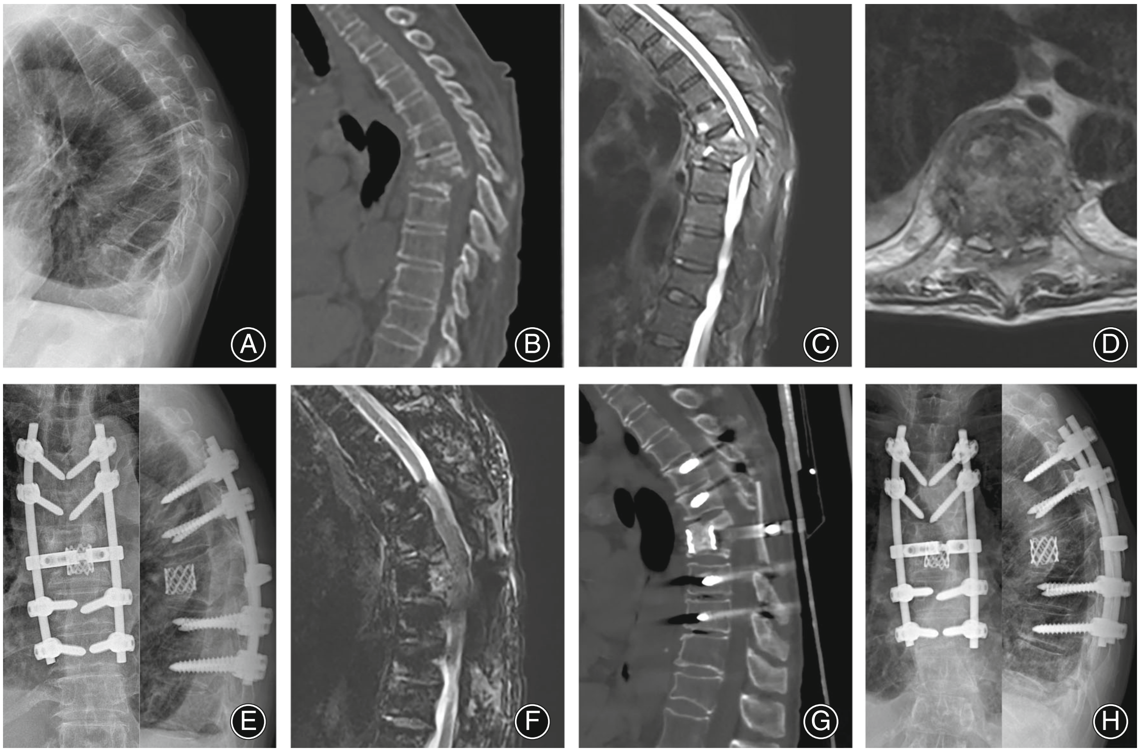

Fig. 1 A 61-year-old woman with T7-8 spinal tuberculosis underwent a posterior interbody fusion procedure with a titanium mesh cage. Preoperative X-ray, CT, and MRI showed vertebral body destruction, collapse, and severe kyphosis, which involved the spinal cord, resulting in neurological deficit. The preoperative Cobb's angle was 37° (A–D). Postoperative radiography revealed internal fixation, and the titanium mesh cage was in a good position. MRI showed that spinal cord compression was relieved. The postoperative Cobb's angle was 27° and internal fixation was in a good position (E, F). The FFU radiographs at 36 months showed good bone fusion, and the Cobb's angle loss was only 2° (G, H)

chemotherapy were employed to treat local abscess recurrence experienced in two cases in the ALB group. Pseudarthrosis was observed in two cases in the ALB group, for which they underwent anterior titanium mesh cage bone grafting. No graft fracture, sliding, or resorption was observed in the other two groups (Figs 1–3).

Discussion

Characteristics of Mid-thoracic Spinal TB and Necessity of Surgical Treatment

Backache and paraplegia are common initial symptoms of thoracic spinal TB as revealed by a retrospective, observational study. This is inseparable from the inherent anatomical characteristics of the thoracic vertebra. The thoracic vertebrae form a closed cavity with the ribs and sternum, which is relatively stable and has poor mobility. Stable thoracic joint support limits motion, besides, the buffer space of the thoracic spinal canal is relatively narrow and the blood supply to the thoracic spinal cord is low. As the disease develops, caseous necrotic tissue, pus, and dead bone caused by spinal TB can often invade the spinal canal and lead to compression of the thoracic spinal cord. Vertebral body destruction with consequent collapse causes kyphosis deformity, thus increasing the risk of paraparesis or even paraplegia.[10,11] Therefore, focus clearance and reconstruction of spinal stability are the prerequisites for curing mid-thoracic spinal TB and the key to prevent neurological deterioration.

Selections of Surgical Methods and the Advantages of the Posterior Approach for Thoracic Spinal TB

Combining anterior and posterior approaches or one-stage anterior approach are the two central surgical strategies to address thoracic spinal TB in the past.[12–14] Although the combining approaches improved orthopedic effect and the anterior approach achieves complete debridement of the lesion in front of the vertebral body, the disadvantages of two surgical methods such as large surgical trauma, increased operative time, complex anatomical structures, and high risk of postoperative complications cannot be ignored.[13,15]

Posterior-only surgical treatment for spinal tuberculosis has matured considerably over the last decade. This approach has the advantages of simplicity, less invasiveness, and rapid resumption. Many clinical practices have shown that the one-stage posterior procedure is a safe and effective surgical method for thoracic spinal tuberculosis.[16–18]

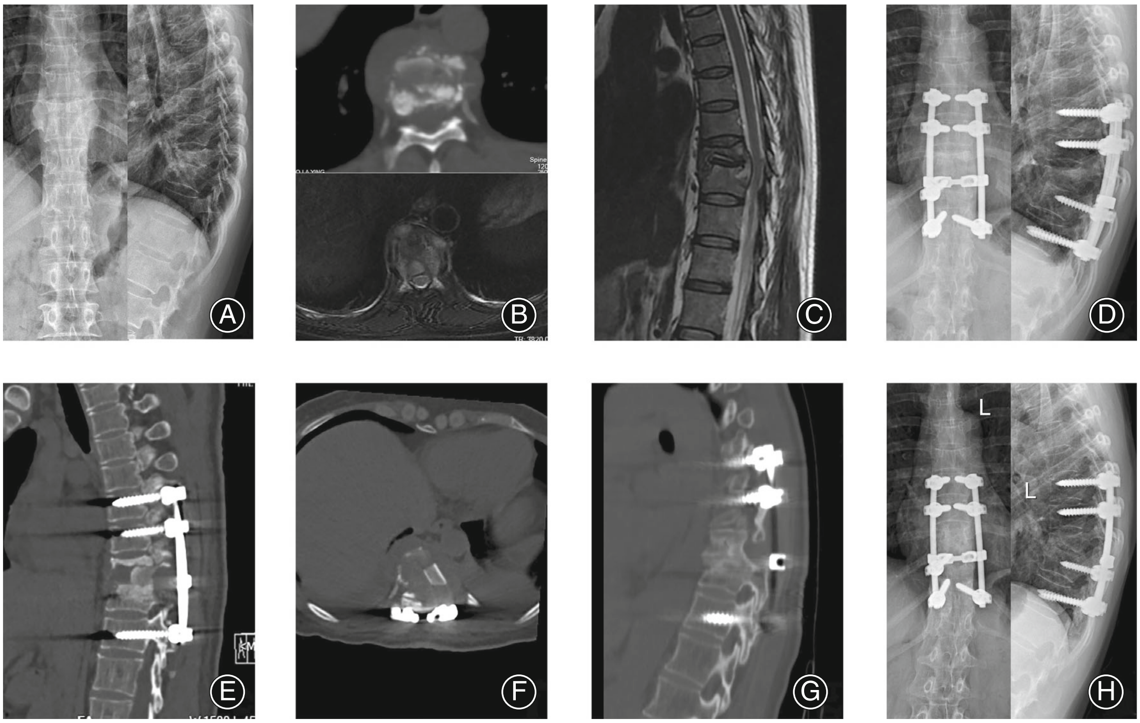

Fig. 2 A 55-year-old female patient with T9-10 spinal tuberculosis received posterior interbody fusion procedure with allogeneic bone graft. Preoperative imaging film showed severe spinal bone destruction with T9 vertebral compression fracture and spinal cord compression. The obvious kyphosis could be observed with a Cobb's angle of 28° (A–C). Postoperative X-ray and CT showed that allogeneic bone graft was in the appropriate size and position. The postoperative Cobb angle was 21° and internal fixation was in good position (D–F). The FFU radiographs at 40 months showed good bone fusion and the loss of Cobb angle was only 1° (G, H)

Kyphosis correction, lesion removal, bone graft fusion, and three-column fixation could be achieved through a single incision. Kyphosis correction and restoration of the normal physiological curvature of the spine could be achieved by mighty holding force offered by posterior pedicle screws, whereby the risk of loosening and fracture of the internal fixation can also be reduced. Posterior intervertebral bone grafting supplemented by intertransverse and interlaminar bone grafting to achieve a 360° fusion can ensure a long-term stability of the spine. Many scholars have reported successful results with posterior-only surgical treatment of thoracic tuberculosis. Zhong *et al.* reported that debridement, decompression, and stabilization could be achieved synchronously through one-stage posterior approach for consecutive multisegmented thoracic tuberculosis.[19]

Spinal tuberculosis is the local embodiment of systemic tuberculosis. Complete focus clearance is only meant to block infection spread and promote healing of tuberculosis foci, although still not being able in itself to achieve asepsis status. The posterior-only procedure can achieve relatively complete debridement in an "effective" operative channel by removing the facet joint, transverse process, costotransverse articulations, and a small rib. The positive environment essential for the survival of Mycobacterium tuberculosis could be destroyed by clearing the necrotic tissues and ossified bone. The rest of the small number of lesions and abscesses could be absorbed by long-term standardized anti-TB chemotherapy post-operatively. Hence, a combined anti-TB chemotherapy and spinal stability reconstruction regimen remains the most efficacious spinal TB treatment.

Comparing the Bone Graft Struts for Reconstructing Anterior and Middle Column

Kyphotic correction is also an important crucial indicator for the evaluation of successful surgical treatment, and in our study, conspicuous correction of kyphotic Cobb's angle was achieved after surgery. Thus, it is important to complete the reconstruction of spinal stability and correction of kyphosis based on the lesions' clearance. As per the 3-columns theory of Denis,[6] the reconstruction of the anterior and middle columns through interbody fusion is pivotal to the long-term efficacy of the posterior procedure. Titanium mesh cages, allogeneic bone grafts, and autogenous bone grafts are the three commonly used interbody graft methods.

Owing to its good osteogenic activity and lack of rejection reaction, autogenous bone remains the gold standard for bone defect repair and interbody fusion.[20,21] In our study, autogenous iliac bone was chosen as the source of autograft bone. However, patients needed to undergo an autogenous iliac extraction procedure, and longer operation time, and

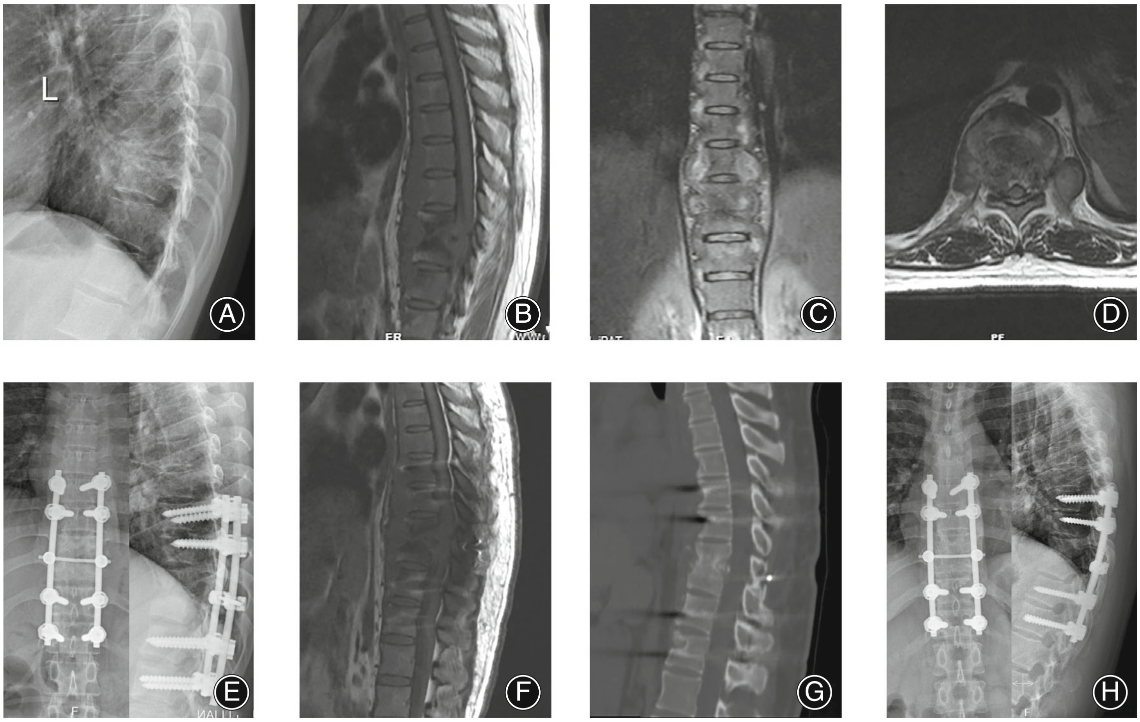

Fig. 3 A 39-year-old female patient with T9-10 spinal tuberculosis received a posterior interbody fusion procedure with autogenous bone graft. Preoperative imaging film showed paravertebral and epidural abscess formation, destruction of bone and spinal cord compression. The preoperative Cobb's angle was 25° (A–D). Postoperative imaging showed that paraspinal and epidural cold abscesses were removed through one stage posterior surgery. The postoperative Cobb's angle was 18° and internal fixation was in good position (E, F). The FFU radiographs at 40 months showed solid interbody bone fusion was achieved and the loss of Cobb's angle was only 2° (G, H)

more trauma or possible donor site problems limited their implementation in clinical practice. In our series, we found that the postoperative VAS score, operation time, and blood loss in the AUB group were significantly higher than those in the other two groups. Allogeneic bone is widely used in spinal surgery at a certain stage of the disease history. Despite its advantage of being easily accessible and not requiring additional surgery compared to the autogenous iliac graft, a lack of blood supply often results in failure of interbody fusion.[22] Moreover, its disadvantages of difficult pruning, poor support strength, easy absorption and occurrence of immunological rejection usually result in failed or prolonged bone graft fusion.[23] In our study, we observed that in the ALB group, the mean fusion time of the bone graft was longer than that in the other two groups, and two cases failed in bone graft fusion and pseudoarthrosis at the bone graft site was observed. Two local abscess recurrence were observed in ALB group and were cured by minimally invasive surgery and regular chemotherapy.

In recent years, several studies supported that titanium mesh cages carry the potential for tried spinal reconstruction, high bony fusion rate, effective sagittal profile balance maintenance and low implant-related problems,[24,25] and the application of a titanium mesh cage filled with osseous granula in the posterior procedure for the treatment of spinal TB has shown commendable clinical efficacy.[26] The titanium mesh cage is usually filled with healthy autogenous osseous granula from the lamina and spinous process, which retains good osteo-inductive ability comparable to that of autogenous bone and provide a large interbody-bone interface that is beneficial to improve spinal stability.[27] Christodoulou *et al.*[28] used a titanium mesh cage filled with cancellous bone granula as a supportive bone material. Follow-up results showed that bone bridges were formed beside the titanium mesh cage, no titanium mesh cage displacement was observed, and no pseudarthrosis was formed; this indicates that the titanium mesh cage supported bone graft can ensure good deformity correction and maintenance and represents a viable alternative to autologous bone grafts. The titanium mesh cage can not only avoid the donor site complications, but can also be tailored to an ideal shape according to the size of the lesion defect to provide mechanically strong support. Zhang *et al.*[29] reported that a specifically shaped titanium mesh was used to reconstruct anterior and middle column through posterior approach surgery, which achieved satisfactory clinical efficacy for treating adults with thoracic spinal tuberculosis. Whether implanting a titanium mesh cage in the lesion area may likely lead to TB recurrence is a major concern of certain scholars. However, numerous studies have demonstrated that titanium is biocompatible and TB bacilli have weak adhesion to titanium strut and do not influence the penetration of anti-TB drugs into lesions.[30,31] In this study, all the patients of the

TMC group successfully attained bony fusion and no abscess recurrence and no pseudarthrosis was observed compared to the ALB group. In contrast, the blood loss and operation time were significantly less than that in the AUB group and donor site pain was avoided. Also, the bone graft fusion time was significantly shorter than that in the ALB group, and no significant statistical difference compared with the AUB group was seen, which revealed the good osteo-inductive ability of titanium mesh cages.

Strengths and Limitations

This study established that one-stage posterior debridement, interbody fusion, and instrumentation can effectively treat mid-thoracic spinal tuberculosis, furthermore, this is an original report of a comparative study to evaluate the efficacy of three bone graft materials for interbody fusion through posterior approach for mid-thoracic spinal tuberculosis in adults. This study also has some limitations. First, this is a retrospective and single-center study, which may lead to biased results. In addition, the sample size of this study is limited. Thus, further prospective studies in larger samples and multi-center analysis are required.

Conclusions

For patients with mid-thoracic TB, posterior approach can effectively restore the spinal stability by reconstructing the anterior and middle spinal columns. In our cohort, from the perspective of the operation itself, postoperative recovery, and successful fusion rate of bone graft, it seems that one-staged posterior instrumentation, focus debridement, and interbody fusion with titanium mesh cages are more effective and appropriate surgical methods compared to interbody fusion with allogeneic bone grafts, and autogenous bone grafts for mid-thoracic spinal tuberculosis.

Author Contributions

Dingyu Jiang participated in the design of this study, performed statistical analysis, and drafted the manuscript. Guannan Sun, Runze Jia and Yilu Zhang collected the clinical data and follow-up details of the study and conducted the study. Xiyang Wang and Zhenchao Xu directed the study design and manuscript drafting. All authors read and approved the final manuscript.

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